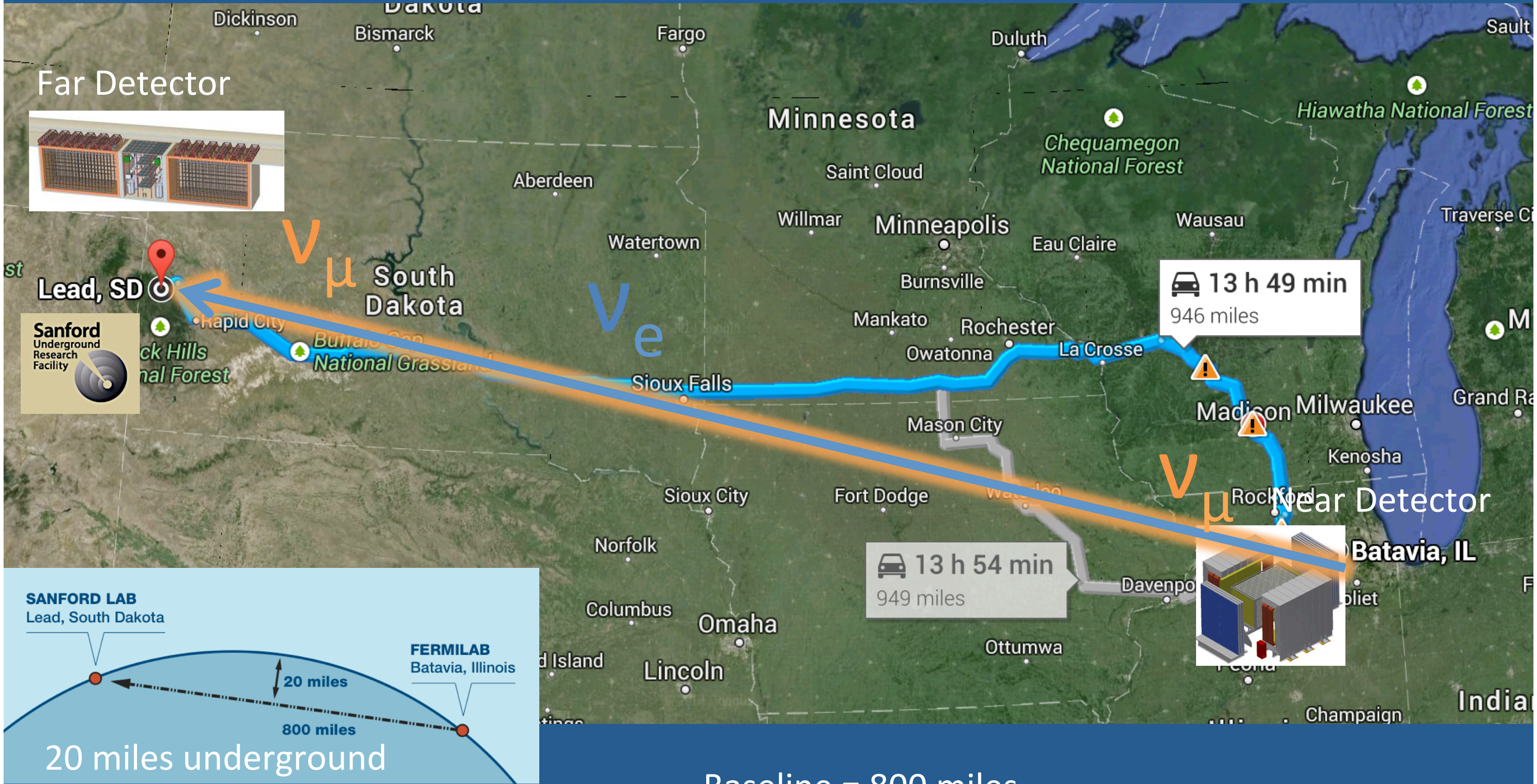
LBNE

Stefan Söldner-Rembold
University of Manchester

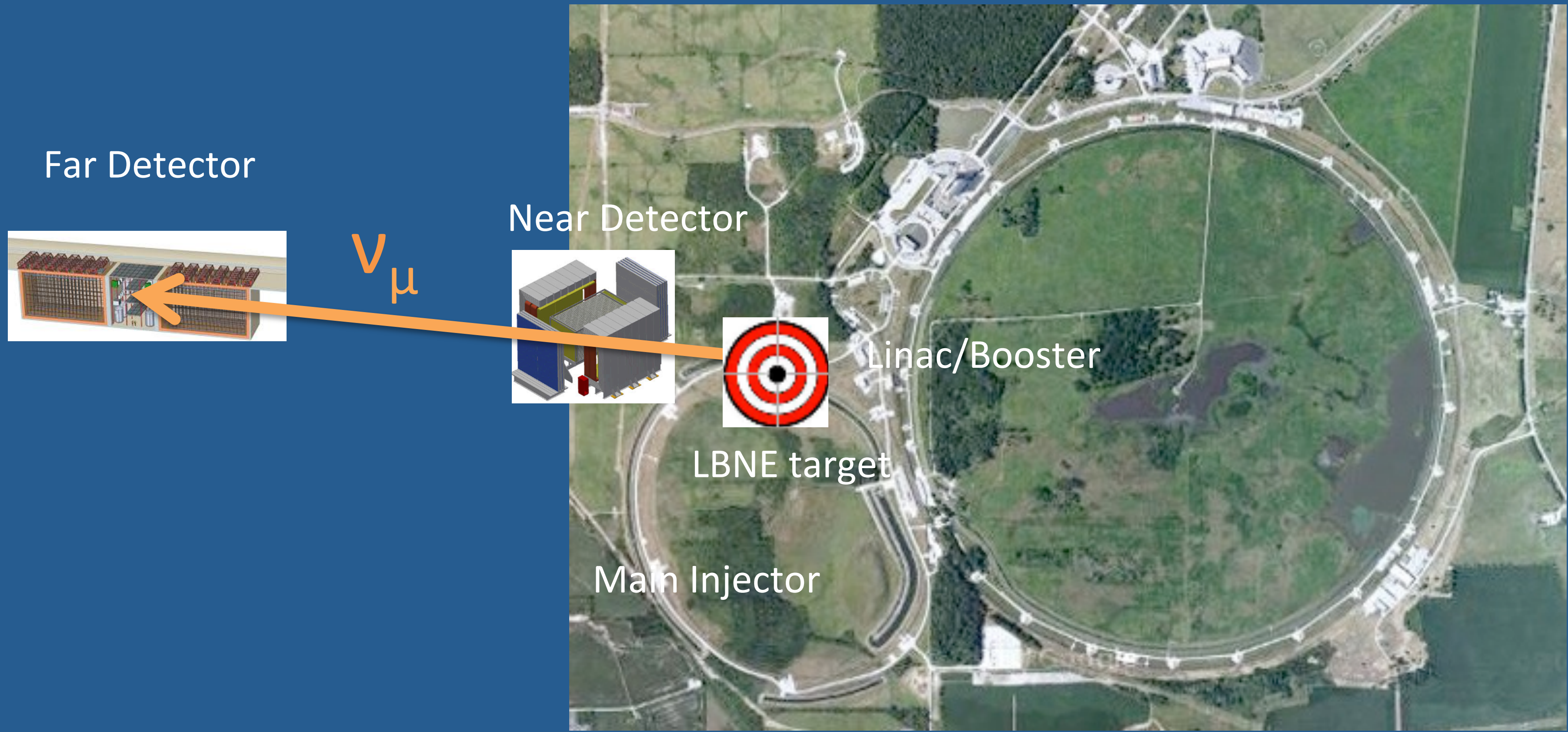
12 June 2014

LBNE Experiment

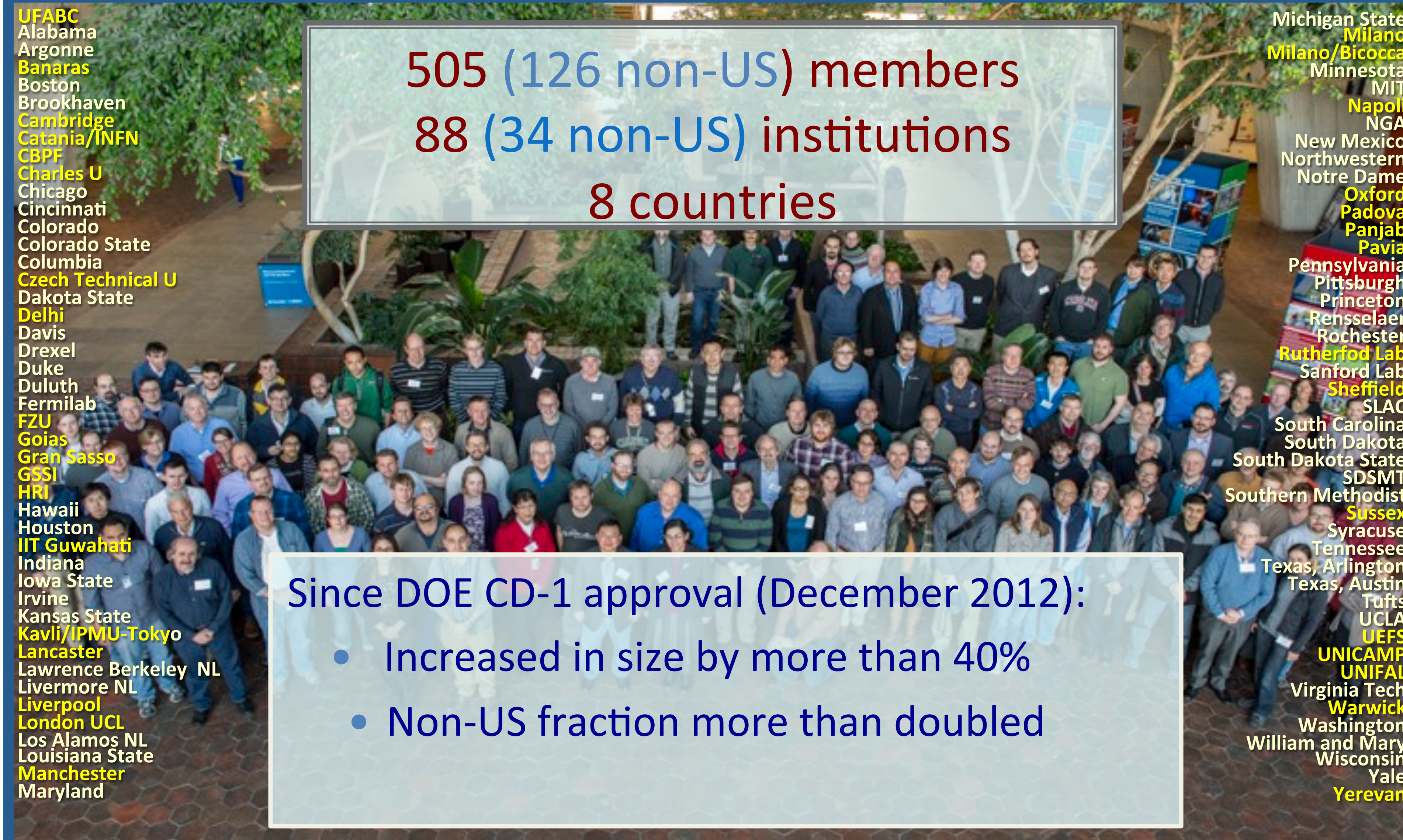


Baseline = 800 miles

LBNE Experiment



LBNE Collaboration



505 (126 non-US) members

88 (34 non-US) institutions

8 countries

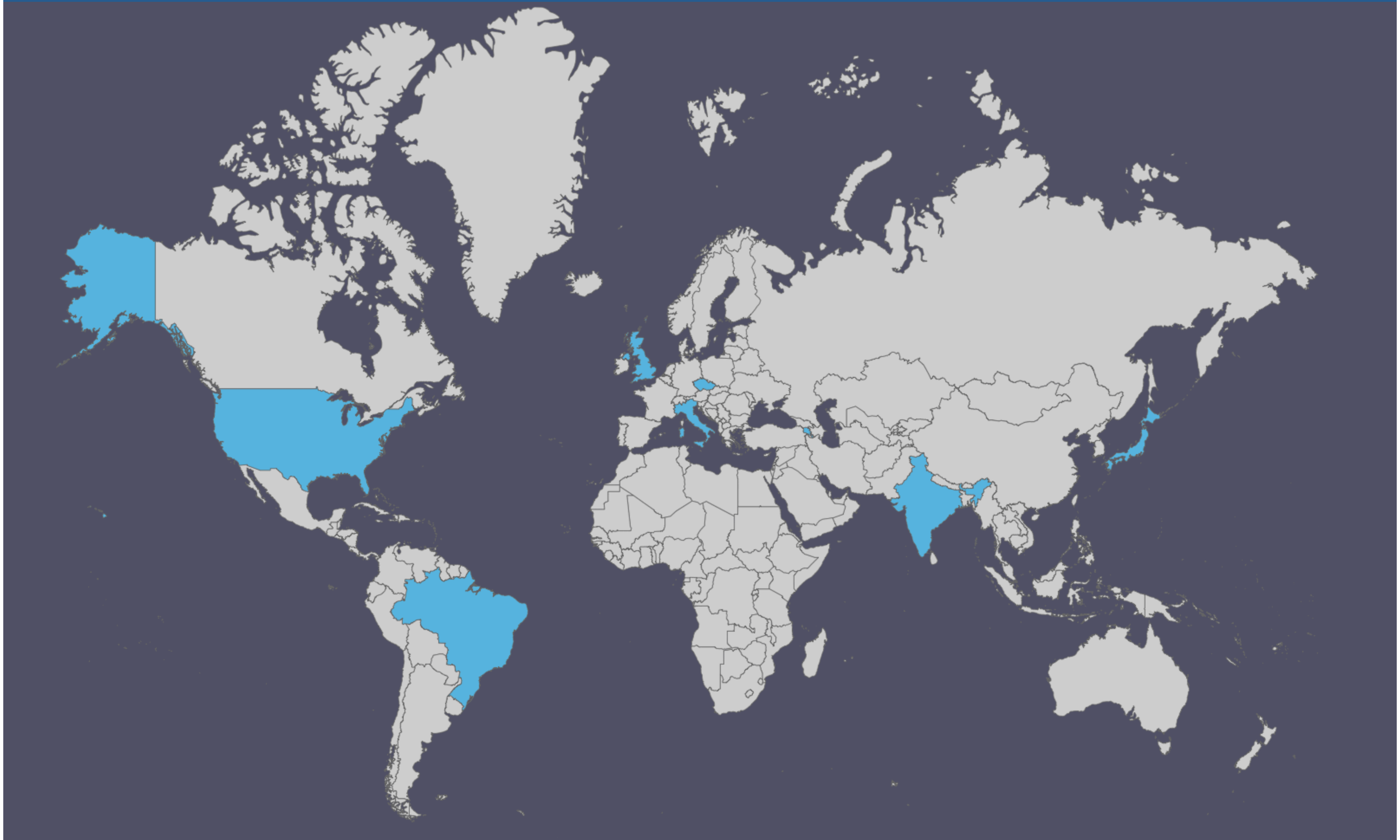
Since DOE CD-1 approval (December 2012):

- Increased in size by more than 40%
- Non-US fraction more than doubled

UFABC
Alabama
Argonne
Banaras
Boston
Brookhaven
Cambridge
Catania/INFN
CBPF
Charles U
Chicago
Cincinnati
Colorado
Colorado State
Columbia
Czech Technical U
Dakota State
Delhi
Davis
Drexel
Duke
Duluth
Fermilab
FZU
Goias
Gran Sasso
GSSI
HRI
Hawaii
Houston
IIT Guwahati
Indiana
Iowa State
Irvine
Kansas State
Kavli/IPMU-Tokyo
Lancaster
Lawrence Berkeley NL
Livermore NL
Liverpool
London UCL
Los Alamos NL
Louisiana State
Manchester
Maryland

Michigan State
Milano
Milano/Bicocca
Minnesota
MIT
Napoli
NGA
New Mexico
Northwestern
Notre Dame
Oxford
Padova
Panjab
Pavia
Pennsylvania
Pittsburgh
Princeton
Rensselaer
Rochester
Rutherfod Lab
Sanford Lab
Sheffield
SLAC
South Carolina
South Dakota
South Dakota State
SDSMT
Southern Methodist
Sussex
Syracuse
Tennessee
Texas, Arlington
Texas, Austin
Tufts
UCLA
UEFS
UNICAMP
UNIFAL
Virginia Tech
Warwick
Washington
William and Mary
Wisconsin
Yale
Yerevan

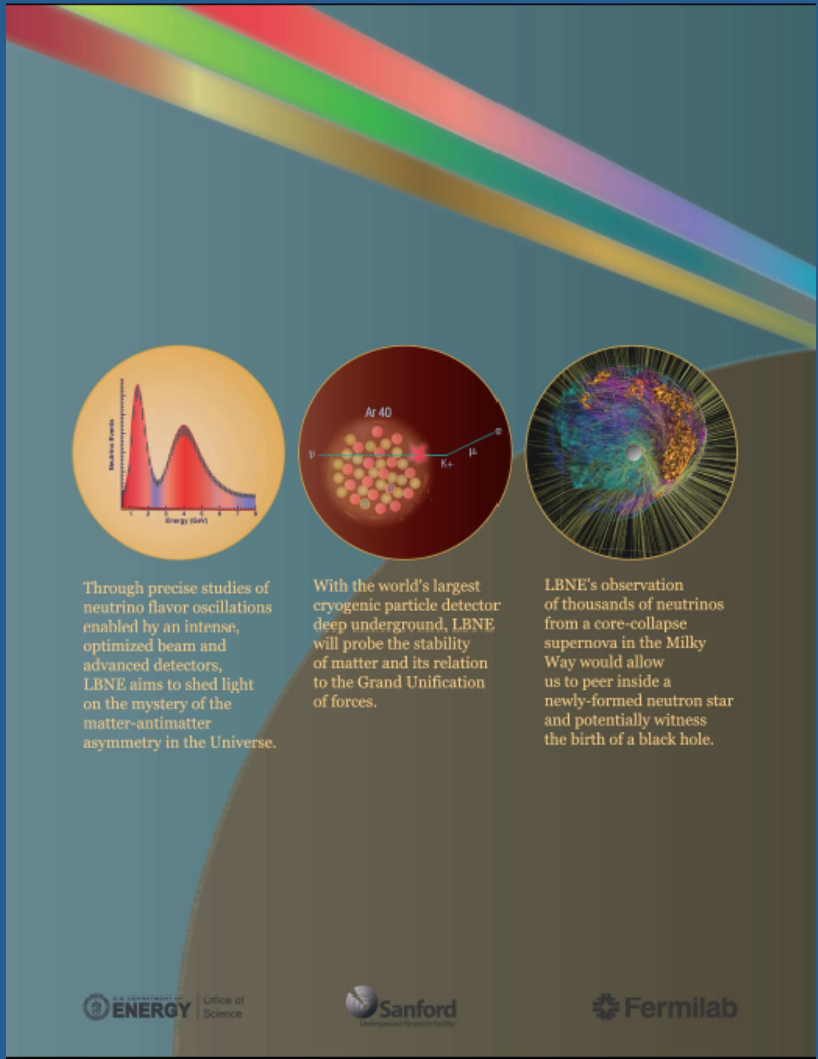
LBNE Collaboration

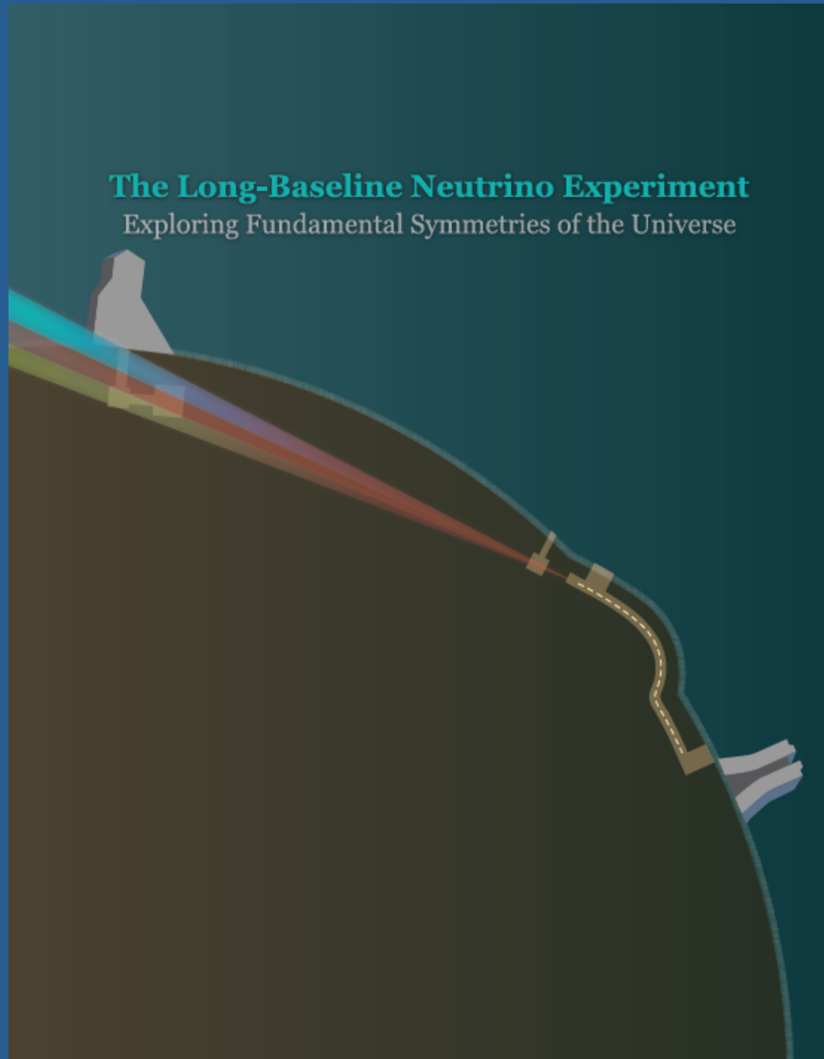


LBNE Science Book

arXiv:1307.7335v3 [hep-ex] 22 Apr 2014

http://lbne.fnal.gov/





Scientific Motivation (1)

CP Violation in neutrino sector

- Observe violation of a fundamental symmetry.
- Is Leptogenesis the answer to matter/antimatter asymmetry?

Neutrino Mass Hierarchy

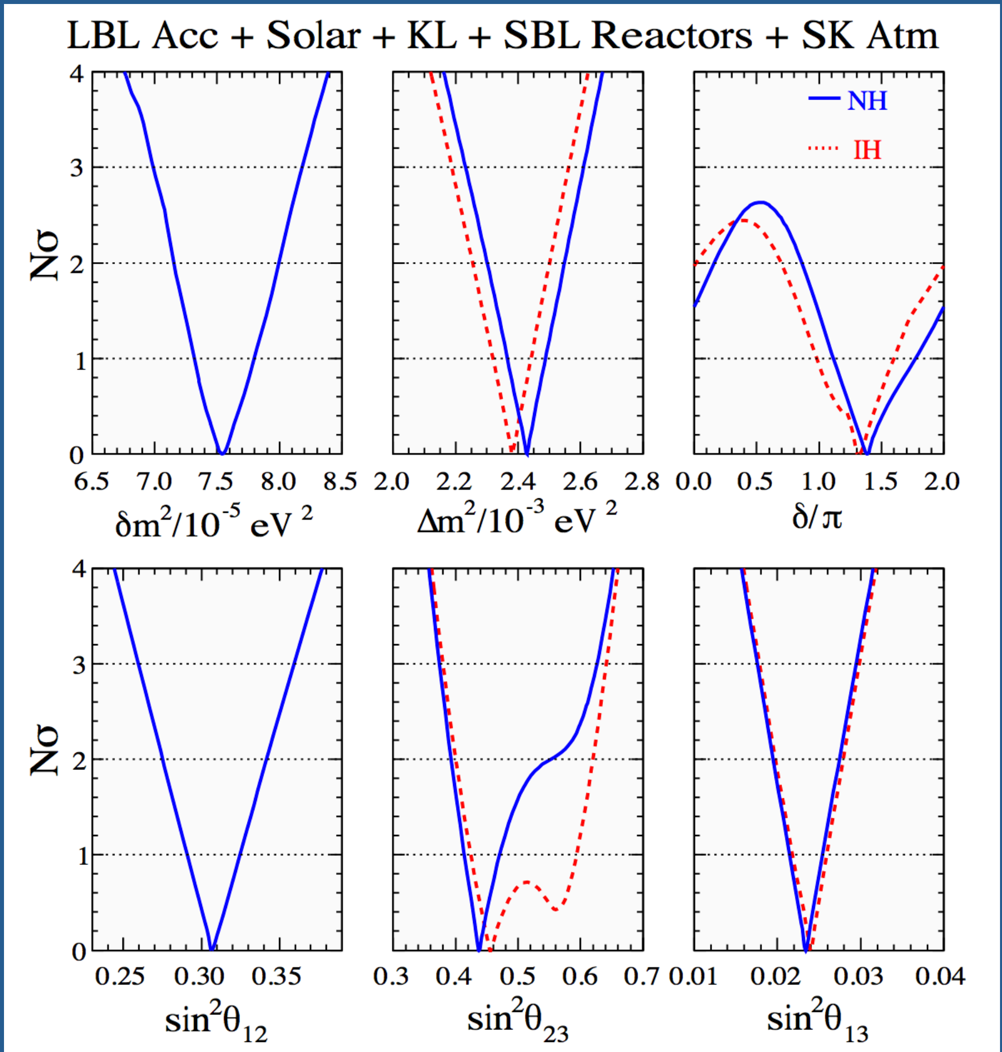
- GUTs, Dirac vs. Majorana nature, implications for $0\nu\beta\beta$ and cosmology.

Testing the Three-Flavour Paradigm

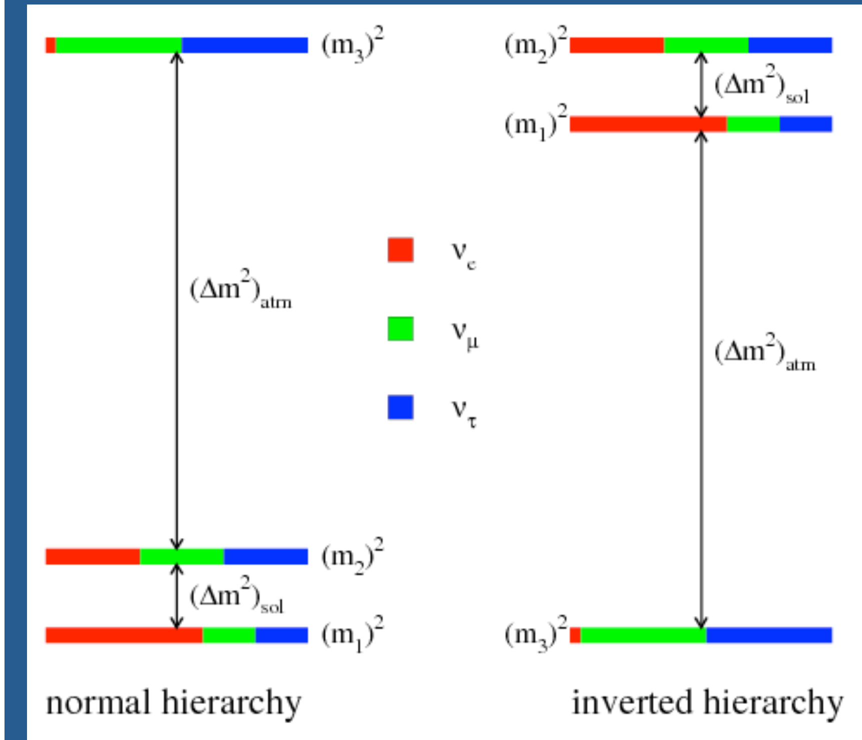
- Precision measurements of known fundamental mixing parameters for neutrinos.
- New physics -> non-standard interactions, sterile neutrinos…
- Precision neutrino interactions studies (Near Detector)

Status Quo & Questions

arXiv:1312.2878

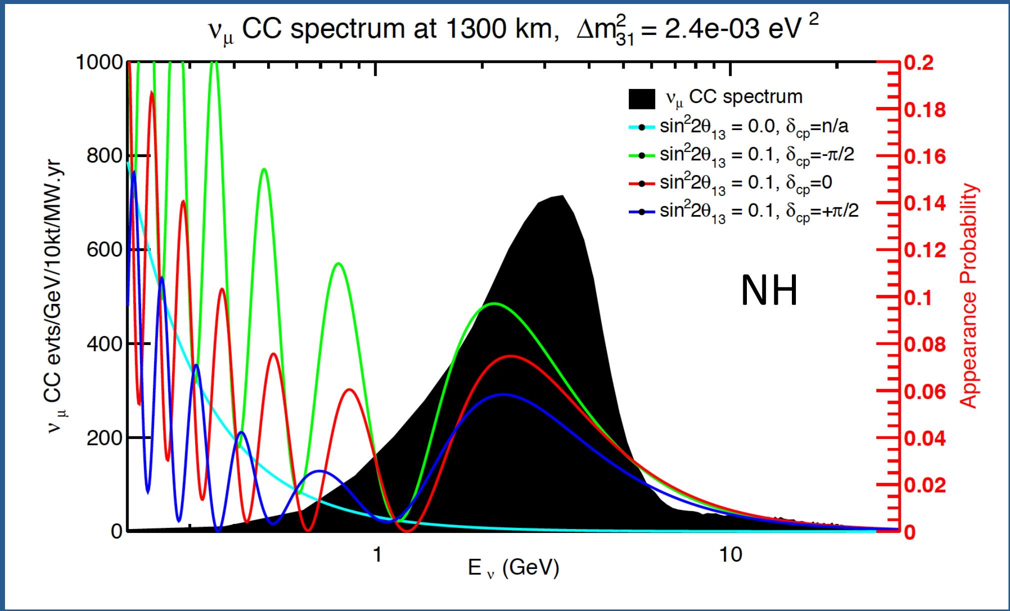


1) Is θ_{23} mixing maximal and which is the right octant ?
2) Is the mass hierarchy normal or inverted ?
3) Is the CP phase $\delta_{CP} > 0$?



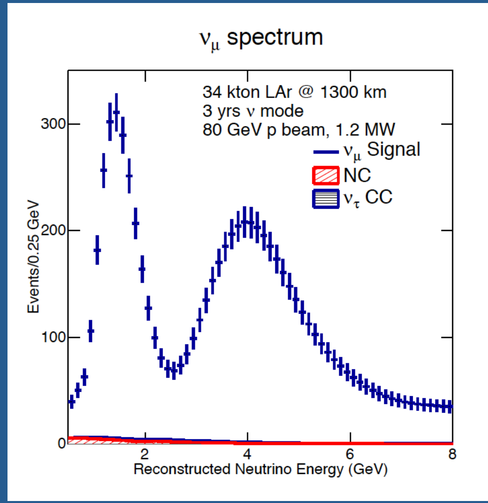
Experimental Technique

- A pure ν_μ beam is generated using the MI proton beam.
- Energy spectrum is matched to oscillation pattern at the chosen distance of L=1300 km.

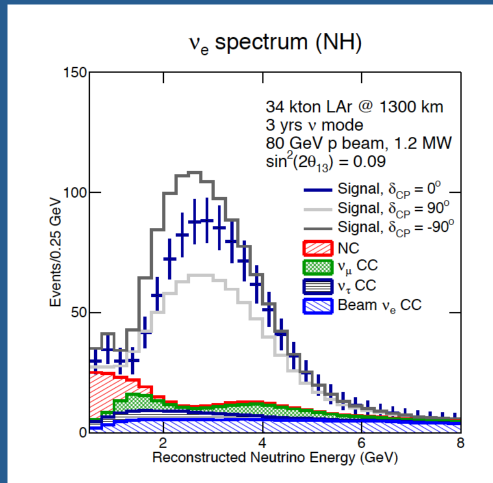


Measure ν_μ and ν_e rates at Far Detector.

≈ 7000 ν_μ events

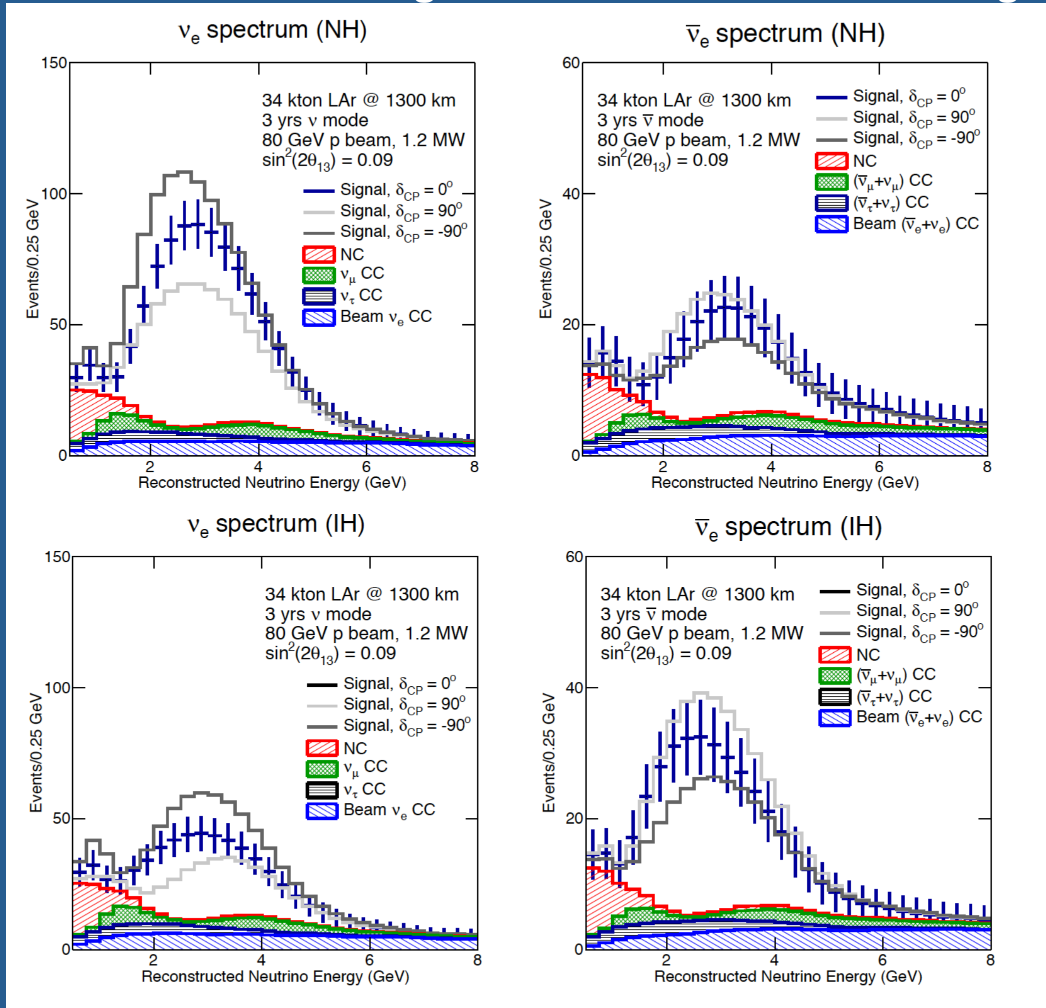


≈ 780 ν_e events



Event Rates at the Far Detector

neutrino running | anti-neutrino running



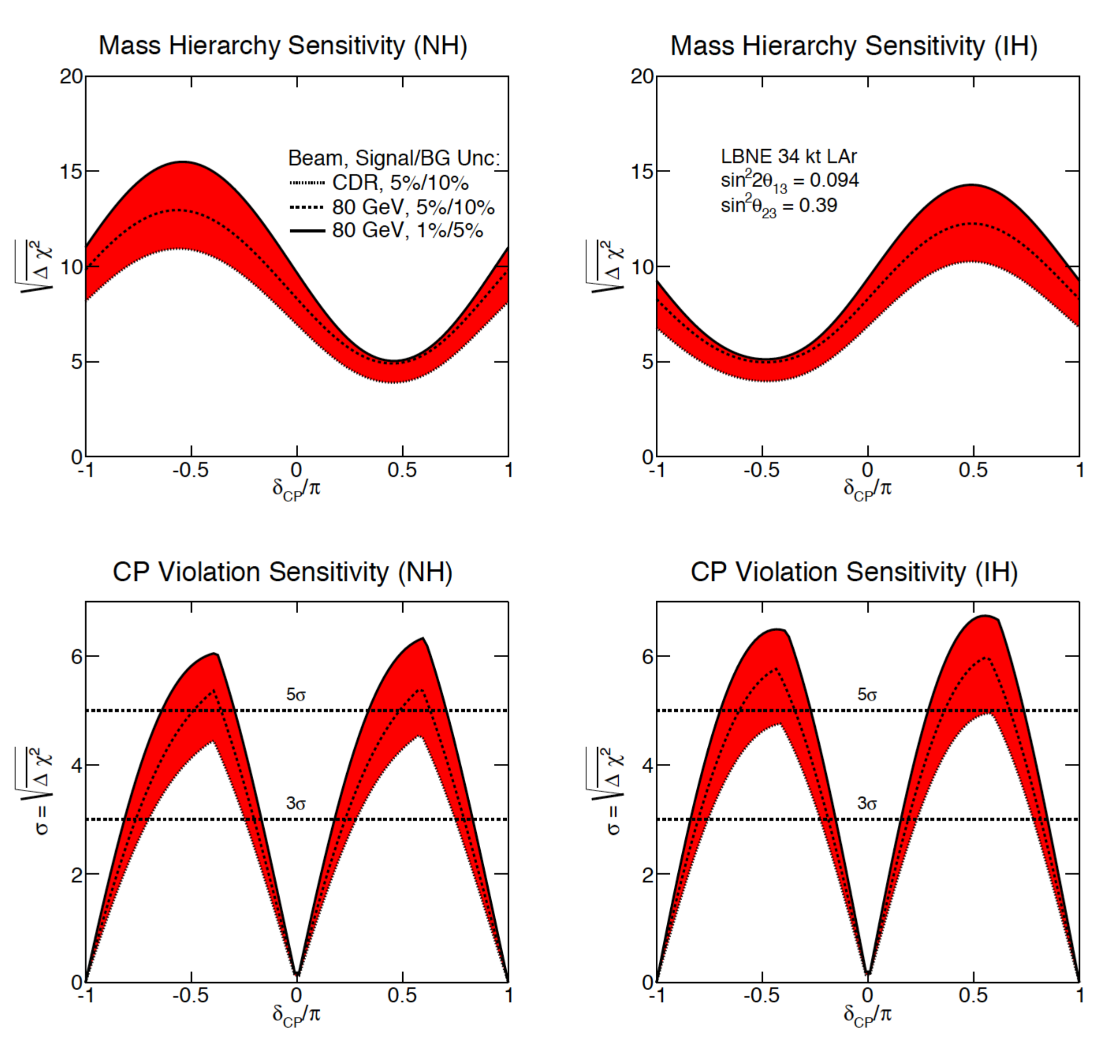
GLoBES simulation with global smearing and efficiencies based on ICARUS.

Three years of running each for neutrinos and anti-neutrinos

Normal Hierarchy

Inverted Hierarchy

MH and CP Sensitivities



Upper band:

optimised beam and systematics

Lower band:

beam not optimised and poor systematics

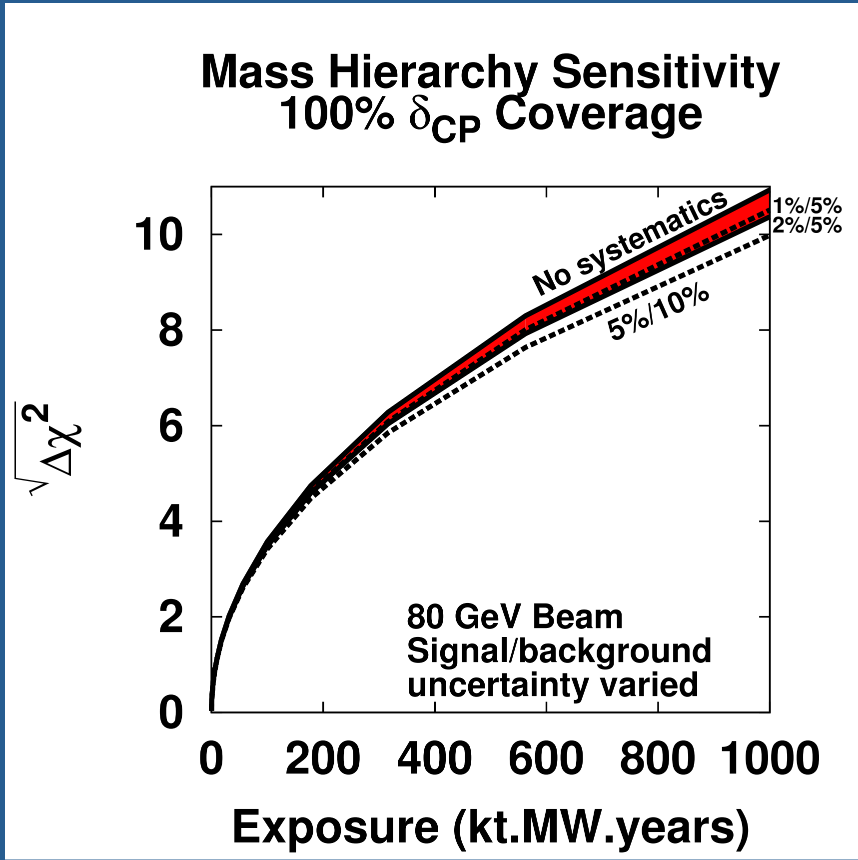
Exposure:

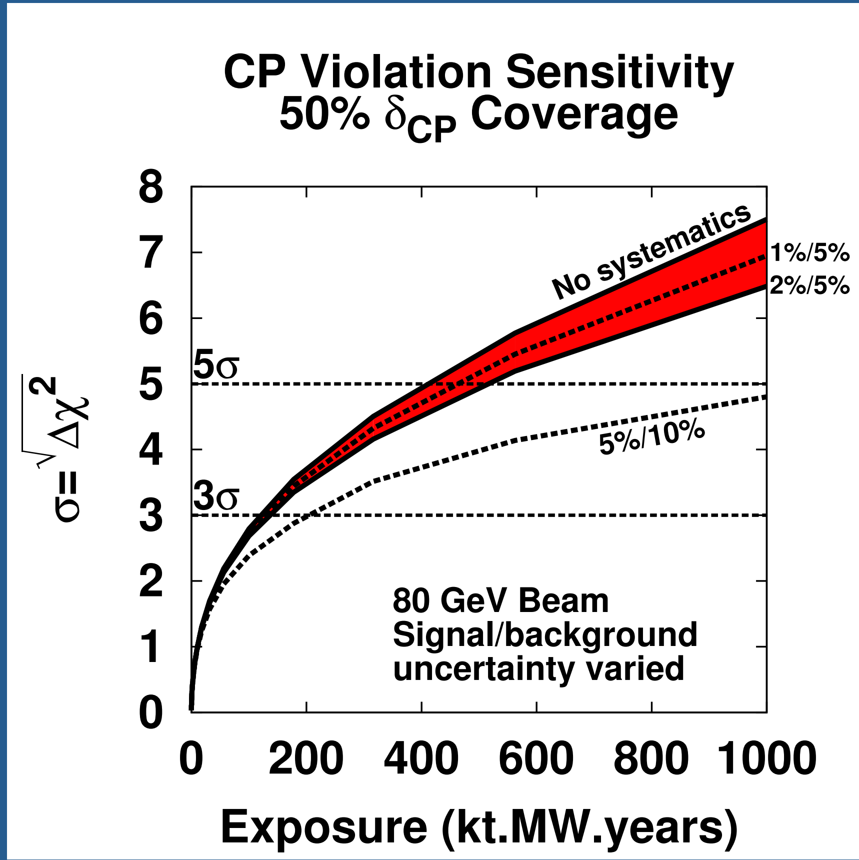
34 kt x 1.2 MW x 6 years (half ν + anti-ν)

Atmospheric neutrinos:

- independent check with $\Delta\chi^2 \approx 4$.
- Increase sensitivity by $\sigma \approx 1$.

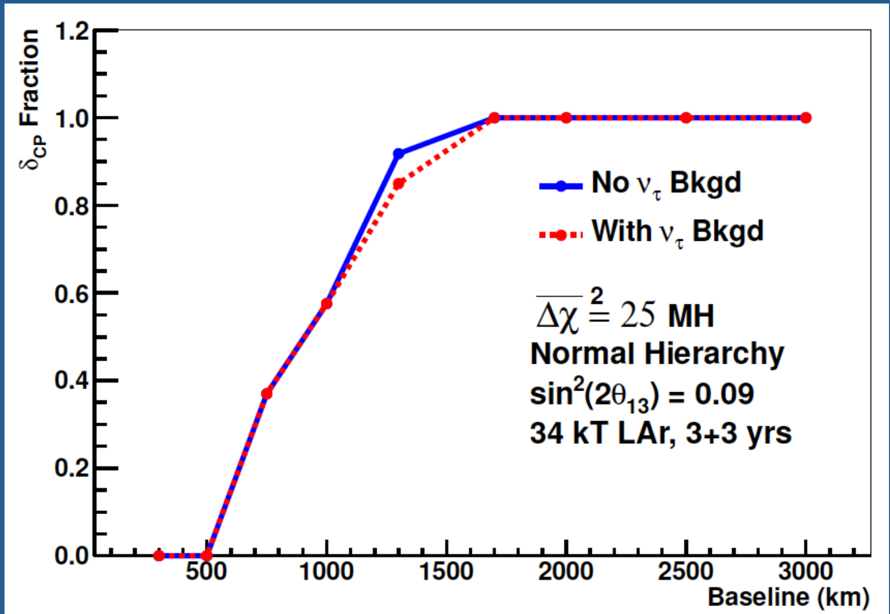
MH and CP Sensitivities



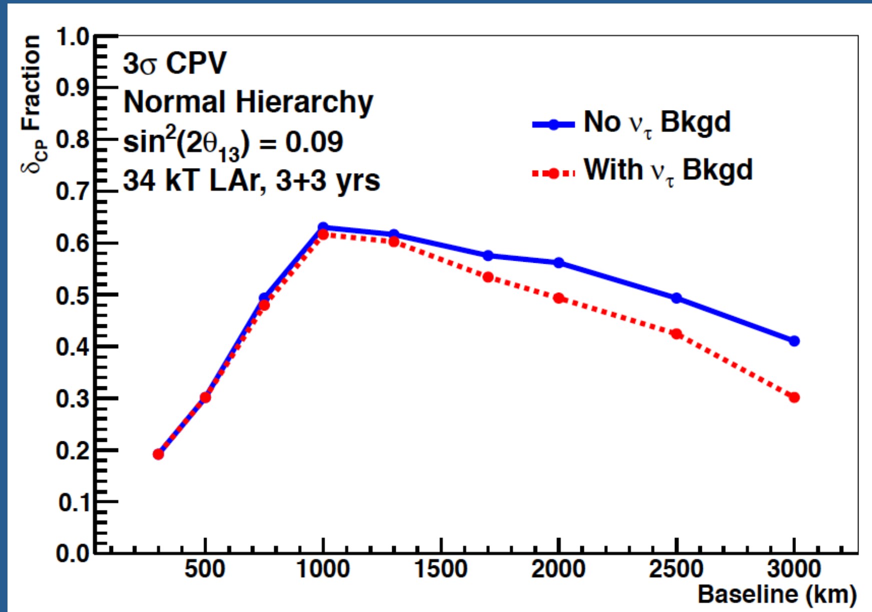


Is the baseline optimal ?

Mass Hierarchy



CP Violation



- Based on simulations for Fermilab NuMI proton beam (120-GeV, 1.2 MW).
  Beam parameters (horn distance, decay pipe length, off-axis beam) optimised depending on distance.

- Baselines 1000-1300 km near optimal.

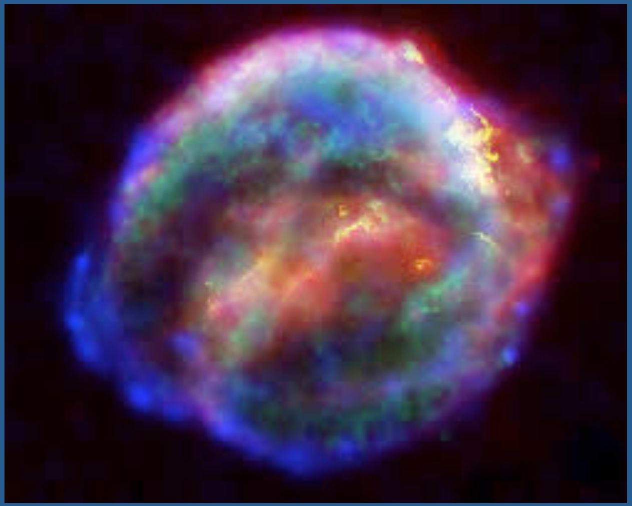
- For very long baselines event rate suppression in one of beam polarities makes observation of explicit CP-violation asymmetry difficult.

Scientific Motivation (2)

Other fundamental physics enabled by massive underground LAr detector:

Nucleon Decay

Is matter stable?
Grand Unification Theory



Astrophysics

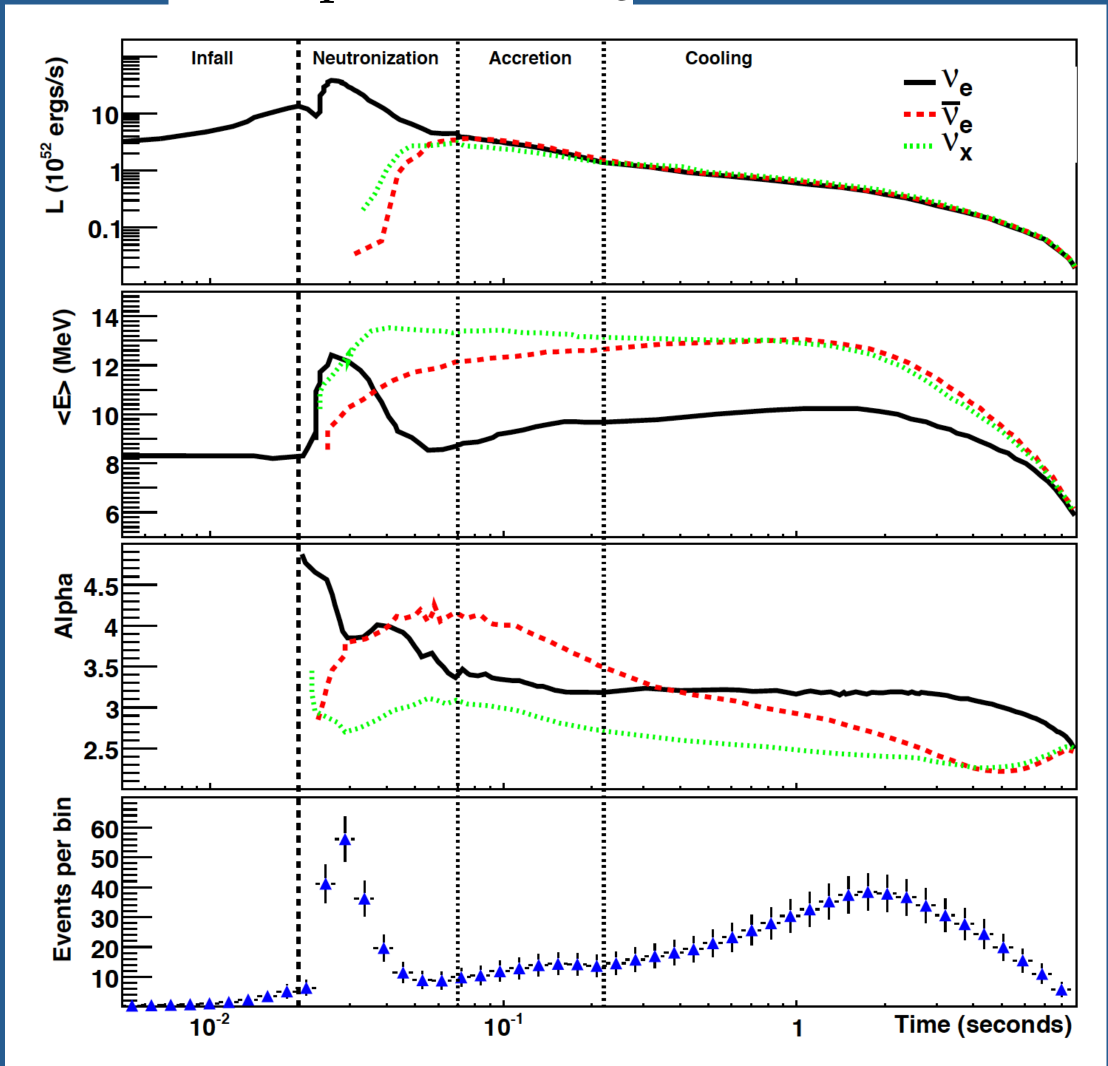
Supernova burst – evolution of a stellar collapse

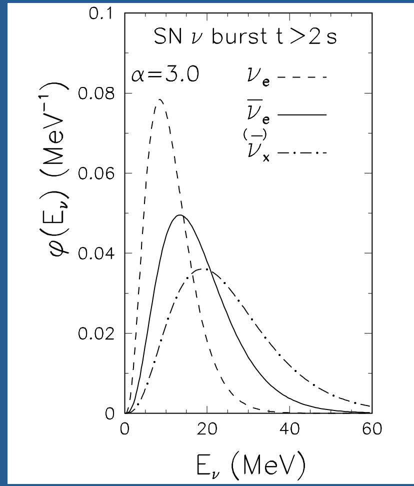
Neutrinos from Supernovae

- About 99% of the gravitational binding energy of the proto-neutron star goes into neutrinos.
- SN at galactic core (10 kpc) will lead to several thousand interactions in 35 kt LArTPC in tens of seconds – reconstructed with a precision < ms.

Neutrinos from Supernovae

$$e^- + p \rightarrow n + \nu_e$$





unique sensitivity through

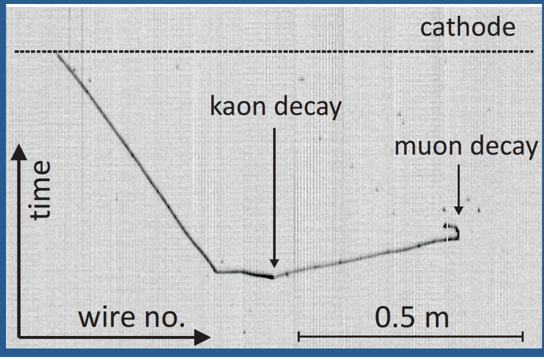
$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

Expect 2-3 core-collapse supernovae in the Milky Way per century

≈ 3000 neutrinos in LBNE for SN@10 kpc

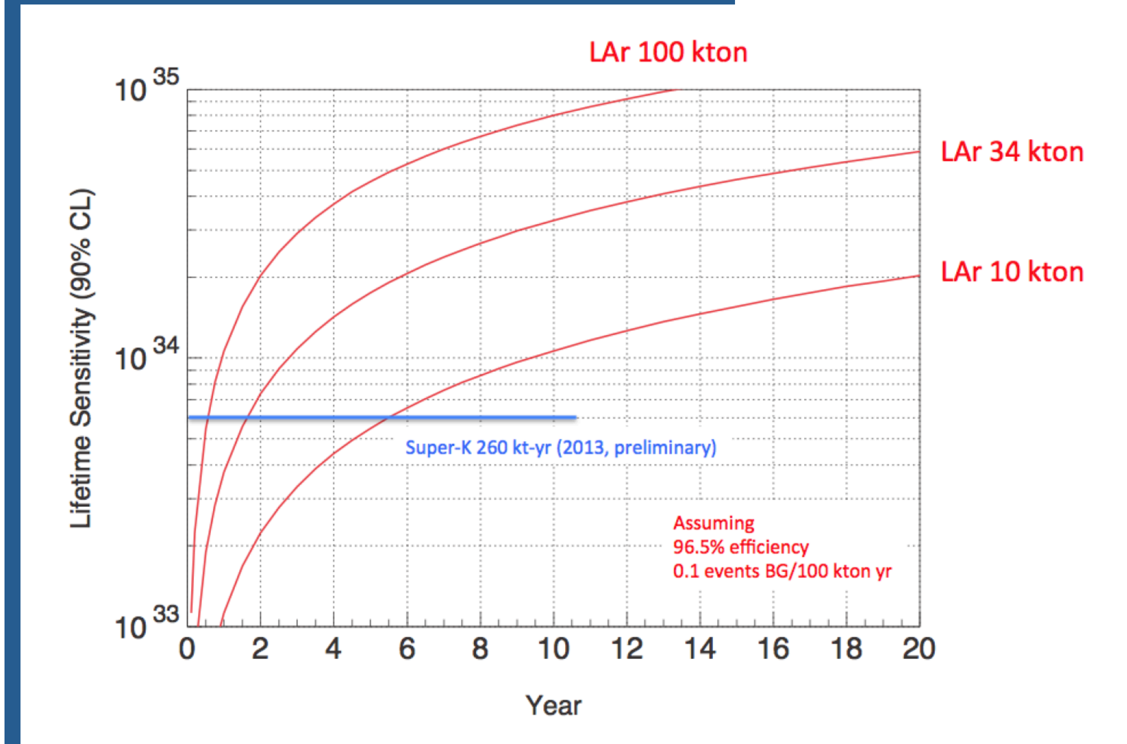
Will we all decay ?

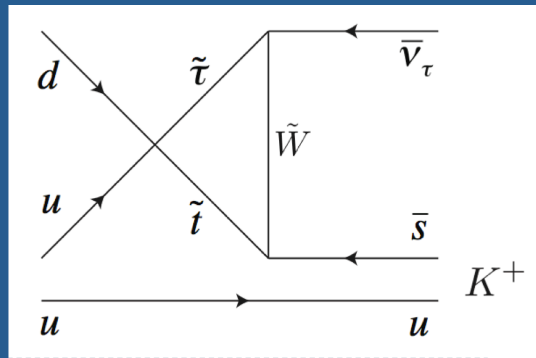
ICARUS



Nucleon decays

Decay Mode	Water Cherenkov		Liquid Argon TPC	
	Efficiency	Background	Efficiency	Background
$p \to K^+\overline{\nu}$	19%	4	97%	1
$p \to K^0\mu^+$	10%	8	47%	< 2
$p \to K^+\mu^-\pi^+$			97%	1
$n \to K^+e^-$	10%	3	96%	< 2
$n \to e^+\pi^-$	19%	2	44%	0.8



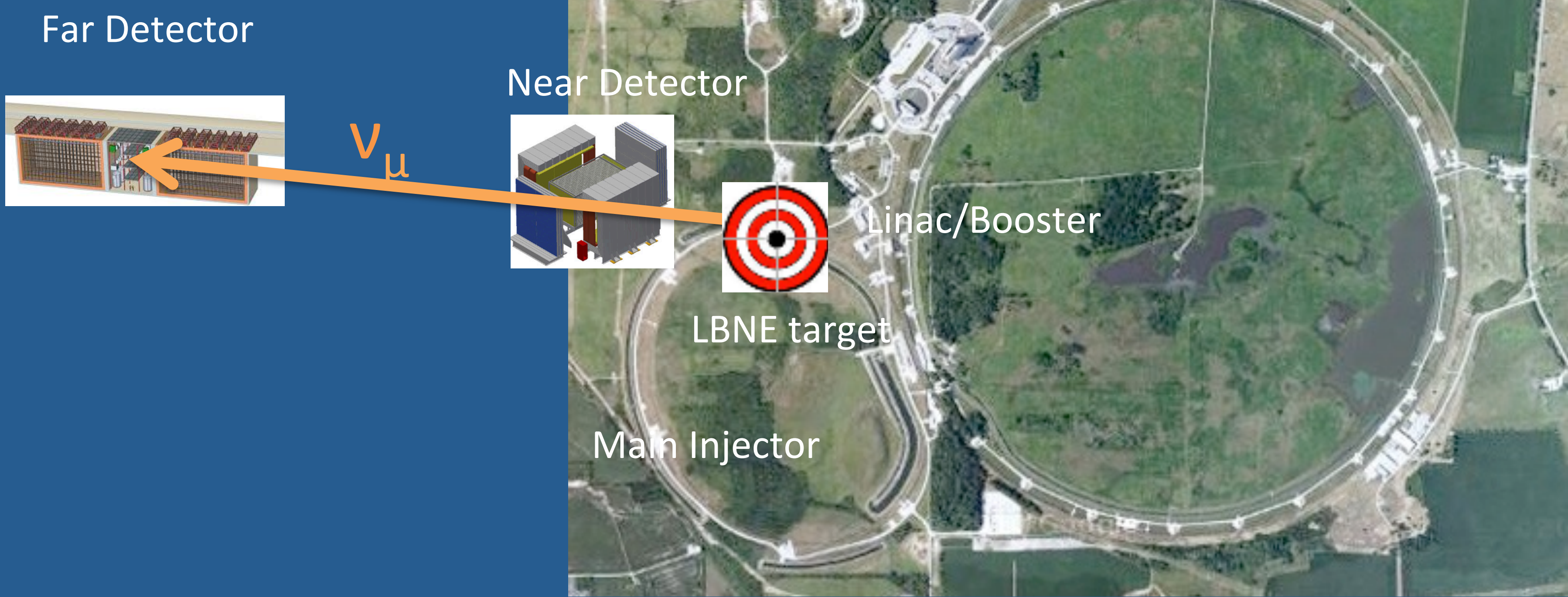


Kaon modes in LAr with high efficiency and low background, leading to high s/b.

Example: SUSY models

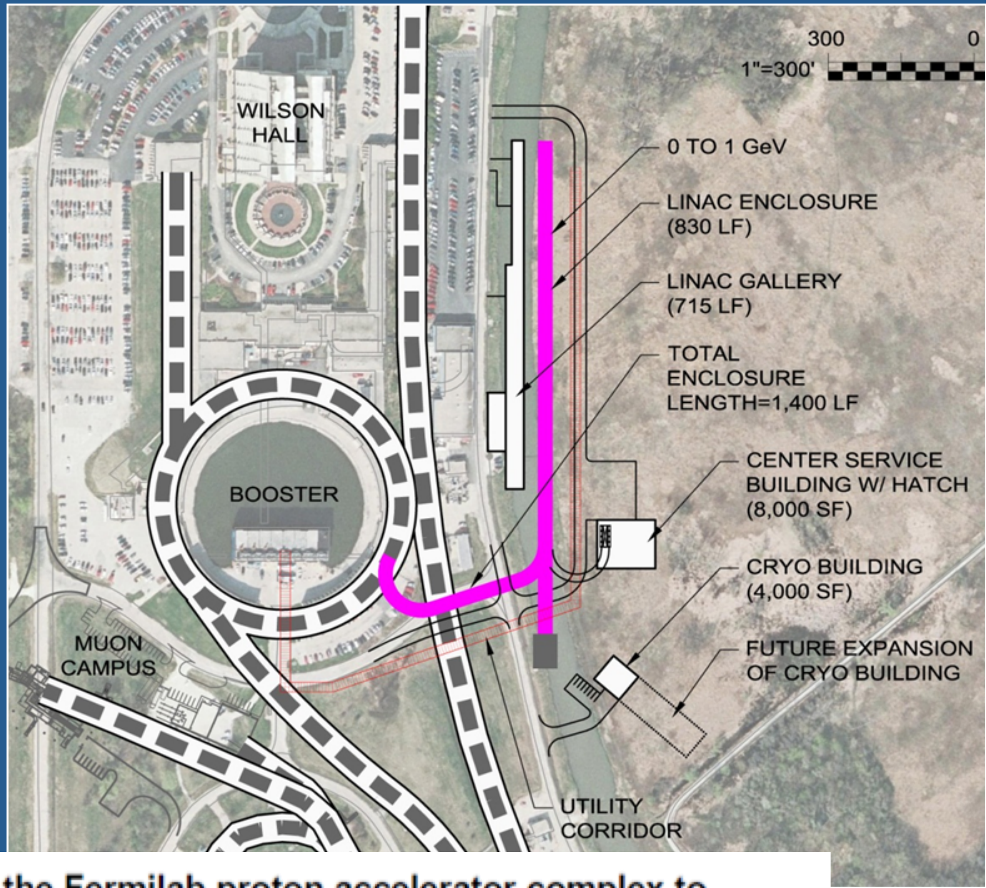
LBNE Experiment

What do we need to do this exciting physics ?   Beam – Near Detector – Far Detector



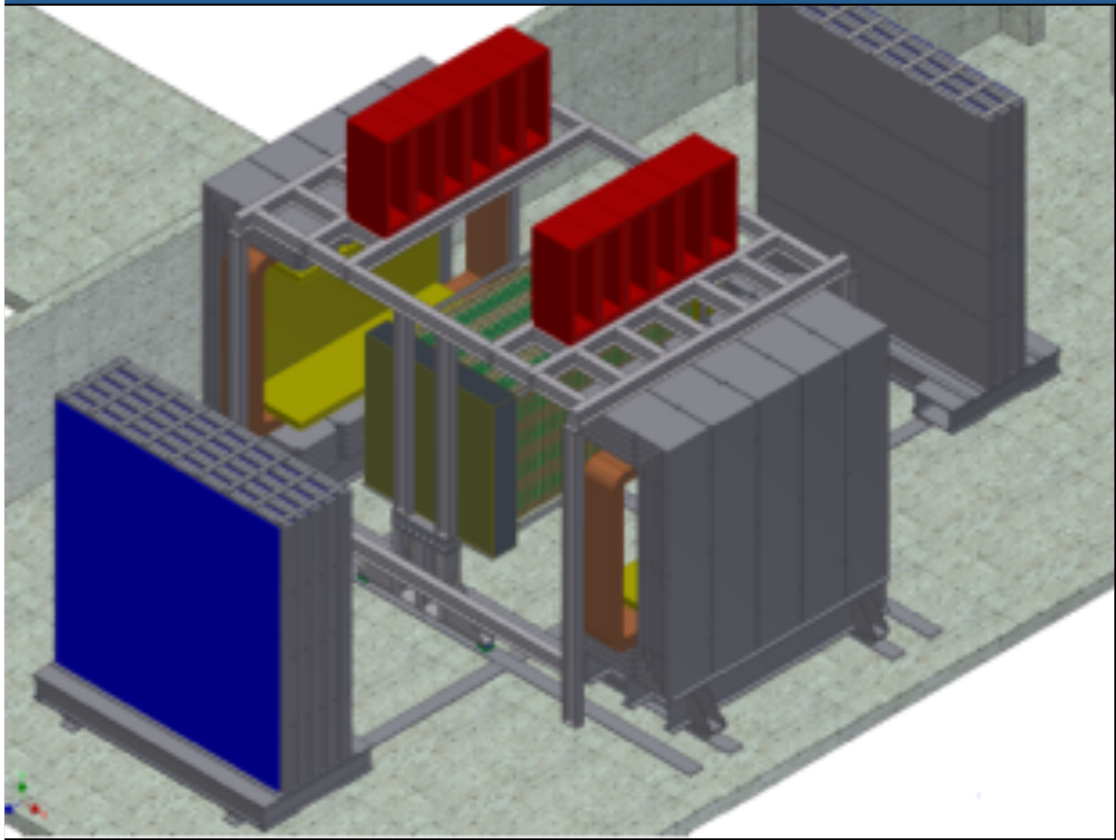
Proton-Improvement-Plan Phase II (PIP-II)

- Replace existing 400 MeV linac with a new 800 MeV superconducting Linac
- 1.2 MW beam power to LBNE at start-up of experiment.
- Plan is based on well-developed superconducting RF technology.
- Strong support from DOE and in the recent Prioritization Panel report.
- Flexible design - future upgrades could provide > 2MW to LBNE.



Recommendation 14: Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility.

LBNE Near Detector



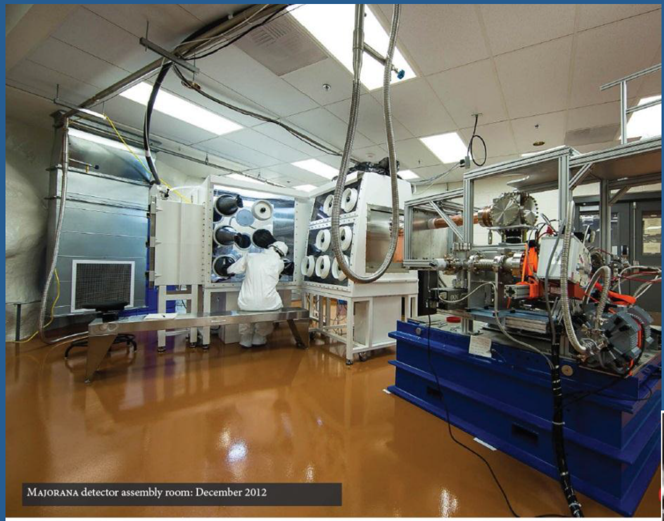
- Fine-Grained Tracker – 460 m from target
  - Low-mass straw-tube tracker with pressurized gaseous argon target
  - Relative/absolute flux measurements
  - High precision neutrino interaction studies
    $\approx 10^7$ interactions/year!
  - Additional target materials possible
  - Proposal pending in India

Sanford Underground Research Facility

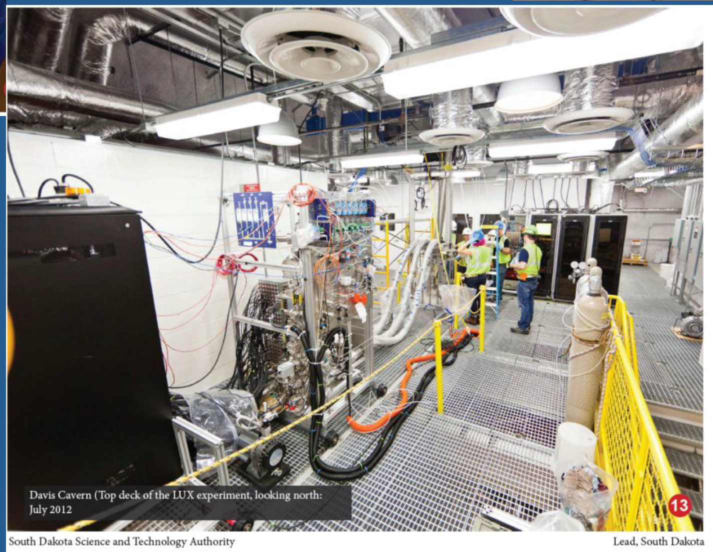
Homestake Mine at at depth of 4300 m.w.e

Entrance to Davis Cavern

Majorana (0νββ)



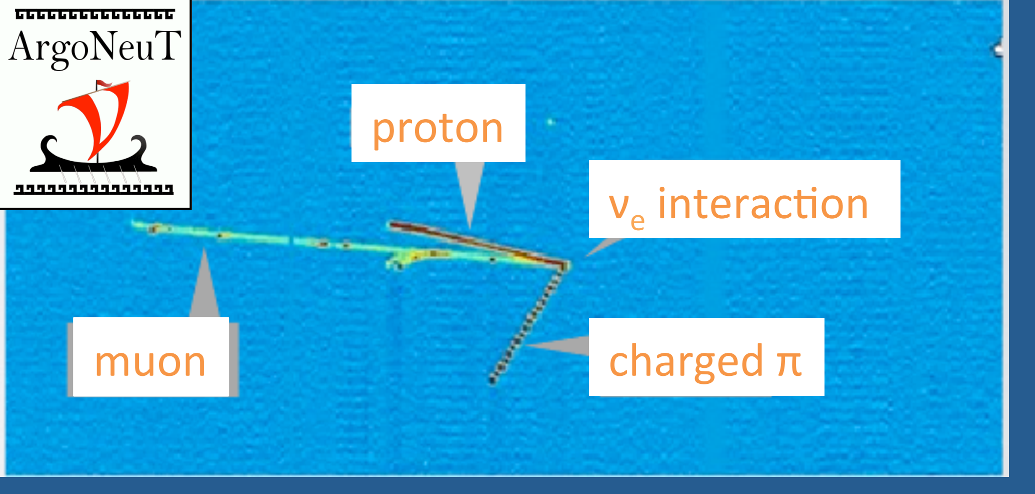
LUX (dark matter)



Liquid Argon Time Projection Chamber

Liquid argon allows for a 'bubble chamber'-like reconstruction
of neutrino interactions.

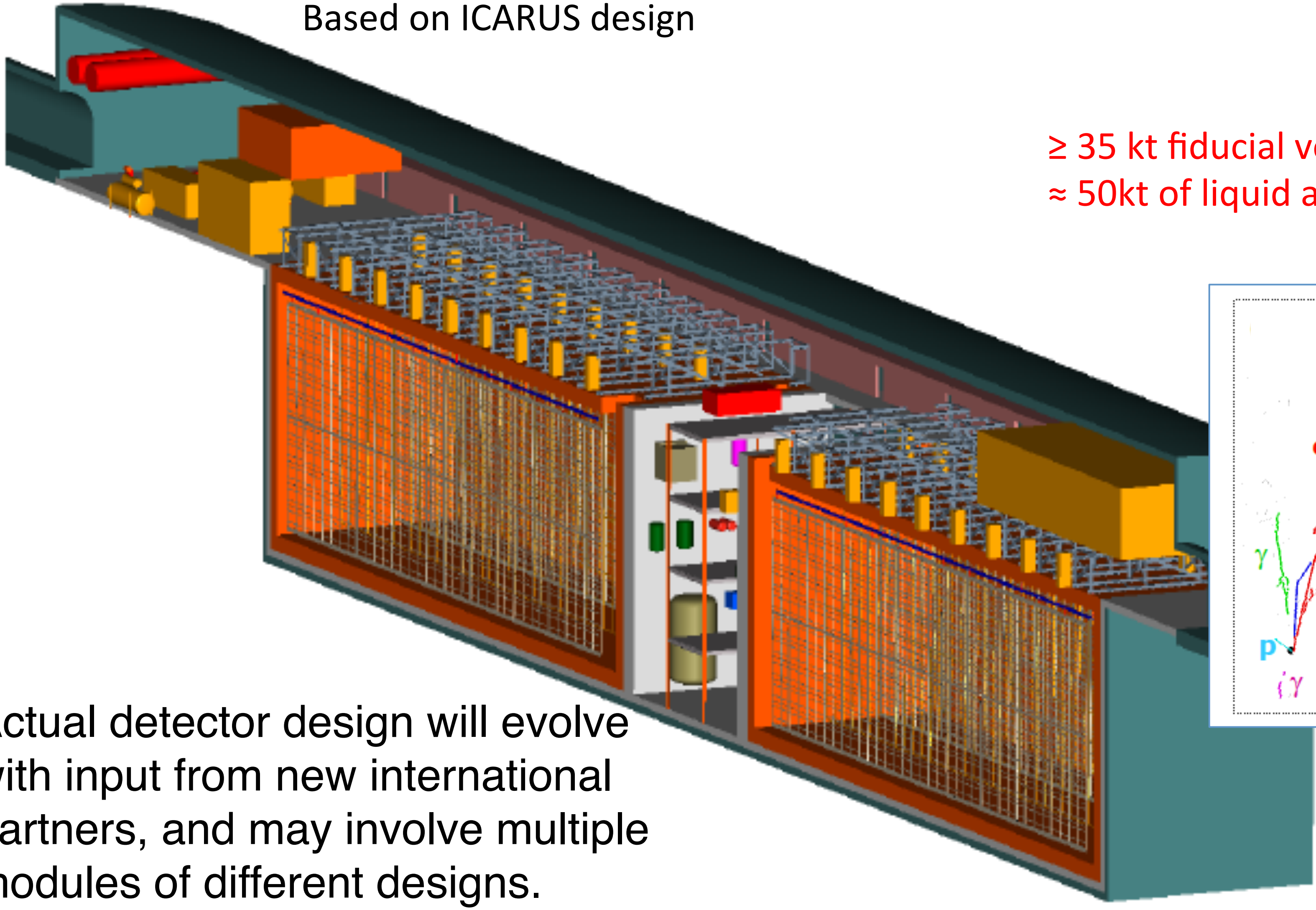
- 3D reconstruction
- Calorimetry
- Particle Identification
- Excellent position resolution



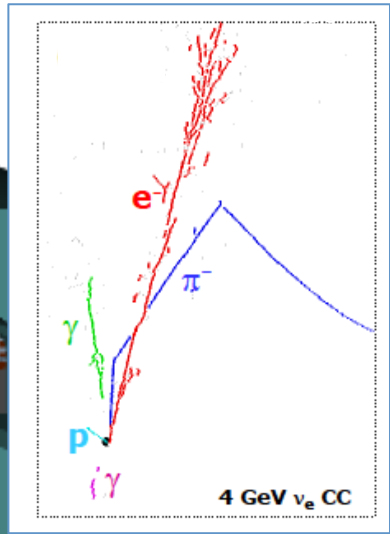
slide A. Szelc, Yale

Current Far Detector Design

Based on ICARUS design

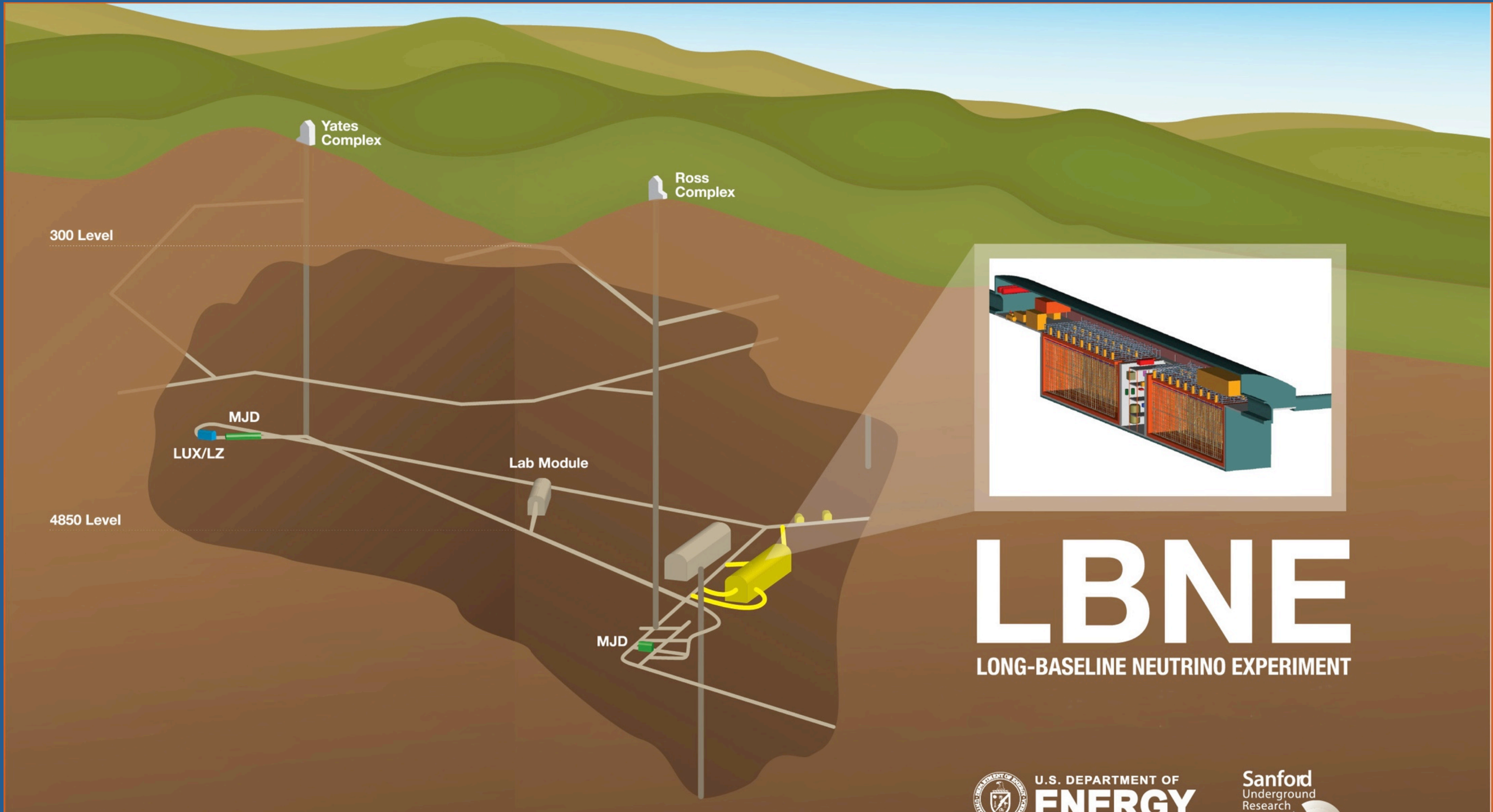


≥ 35 kt fiducial volume
≈ 50kt of liquid argon



Actual detector design will evolve with input from new international partners, and may involve multiple modules of different designs.

Far Detector in Sanford Mine

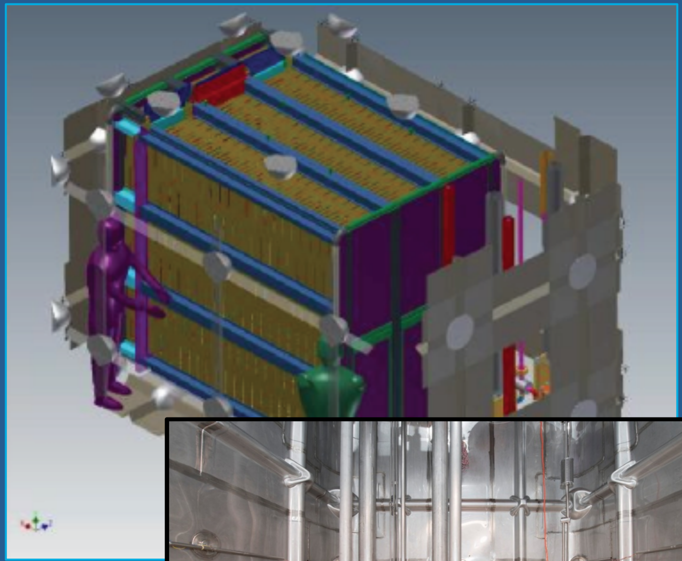


Geotechnical investigations underway
Far detector configuration under development matches P5 recommendation

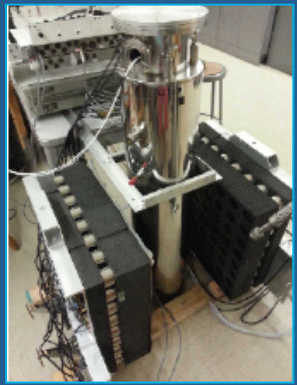
R&D on Far Detector

Just a few examples;

35kt prototype



TPC Anode Plane



Photon detector R&D

Inside cryostat

R&D on liquid argon technology essential for designing and building 35kt detector.

Einstein

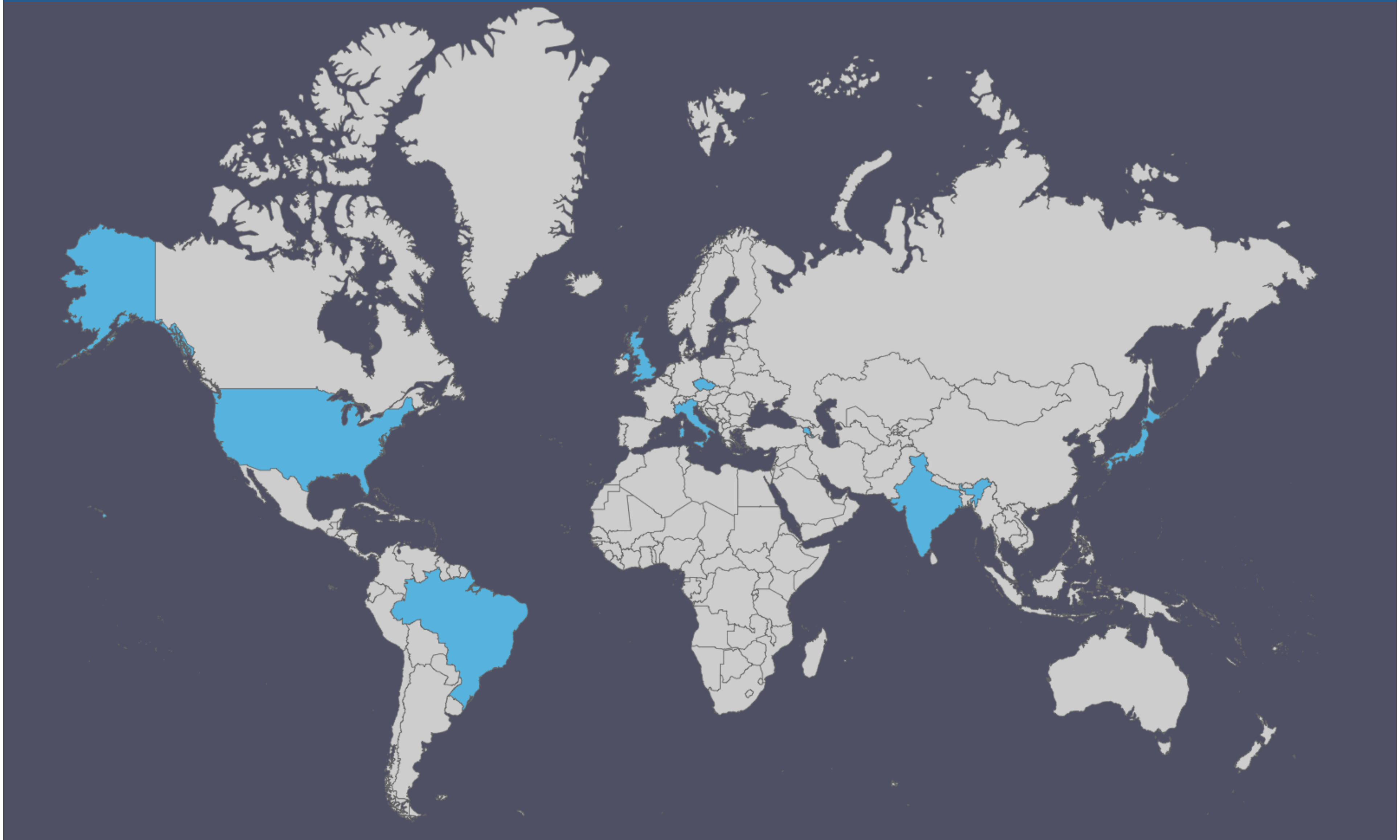
Long-baseline neutrinos

~~LBNE~~
~~LBNF~~
~~LBNG~~
~~LBNH~~
~~LBNI~~
~~LBNJ~~
~~LBNK~~
~~LBNL~~
~~LBNM~~
~~LBNN~~
LBN…

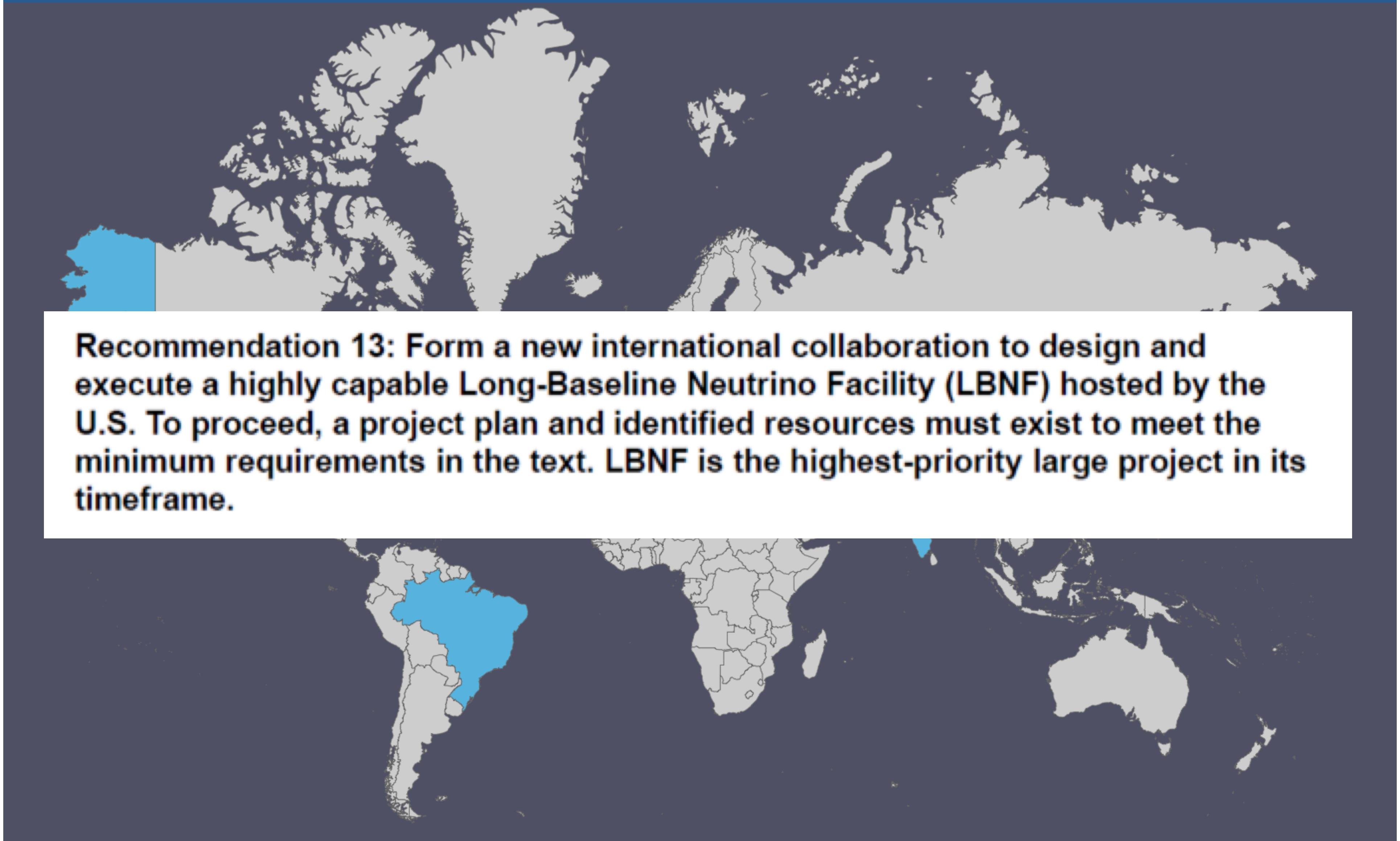
Great ideas often take several attempts

A. Rubbia

LBNE Collaboration



LBNE Collaboration



Recommendation 13: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.

International LBNE Collaboration

Brazil (6 Institutions)

- Proposal to funding agencies (FAPESP and CNPq) to be submitted this year.

India (5 institutions)

- Indian Near Detector proposal under review

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- Work is proceeding to update the scientific requirements on the Near Detector with Indian scientific participation.

- Collaboration workshop planned for July to evaluate the Near Detector design and potential improvement.

International LBNE Collaboration

Italy (8 Institutions)

- ICARUS proposal to bring detector to Fermilab
- More groups have shown interest to join.

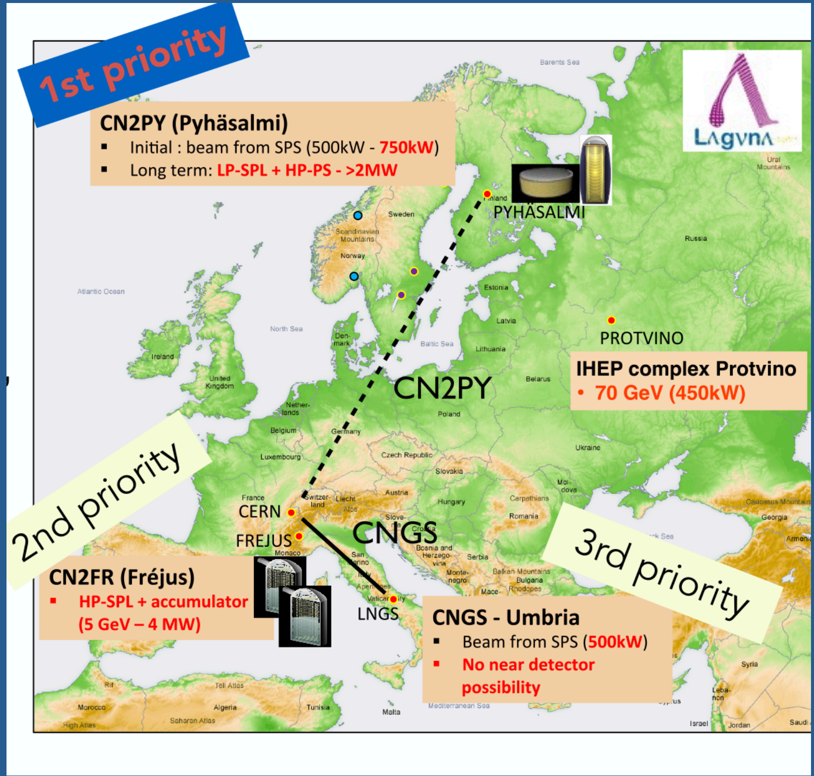
United Kingdom (10 Institutions)

- SoI accepted by funding agency (STFC), proposal now under review.
- Proposal to build part of LArTPC for LAr1-ND.

Potential International Partners

Laguna/LBNO

- European project for LBL LAr experiment from CERN to Pyhäsalmi in Finland.
- Common LBNE-LBNO integration task force formed.



CERN

- Collaboration on several projects (WA104,WA105, beam) under discussion.

Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

Future International Collaboration

LBNE will continue to attract further international participation, based on:

- An exciting world-leading physics programme with a detector concept that can achieve the physics goals (underground, >35kt).

- A well-defined and reliable timeline with first physics starting within a decade.

- An internationally organized Long-Baseline Experiment and Facility.

LBNE-related Projects

Essential for developing large-scale liquid argon technology

- LARIAT – in charged particle beam at FNAL
- CAPTAIN – LArTPC neutron flux at LANL -> FNAL
- LAr1-ND – LArTPC short-baseline in FNAL Booster Neutrino Beam (US/UK)
- ICARUS – LArTPC short-baseline in FNAL Booster Neutrino Beam (Italy)

Will provide crucial input for informing design of LBNE

Alternative approach: Megaton-scale Water Cherenkov

- CHIPS – CHerenkov In mine PitS (UK/US project)
- Water Cherenkov in NuMI beam NOvA -- arXiv:1307.5918

Not recommended by P5, but R&D supported by DOE.

Prototype to be deployed in Wentworth Pit this Summer

LBNE-related Projects

Essential for developing large-scale liquid argon technology

- LARIAT – in charged particle beam at FNAL
- CAPTAIN – LArTPC neutron flux at LANL -> FNAL
- LAr1-ND – LArTPC short-baseline in FNAL Booster Neutrino Beam (US/UK)

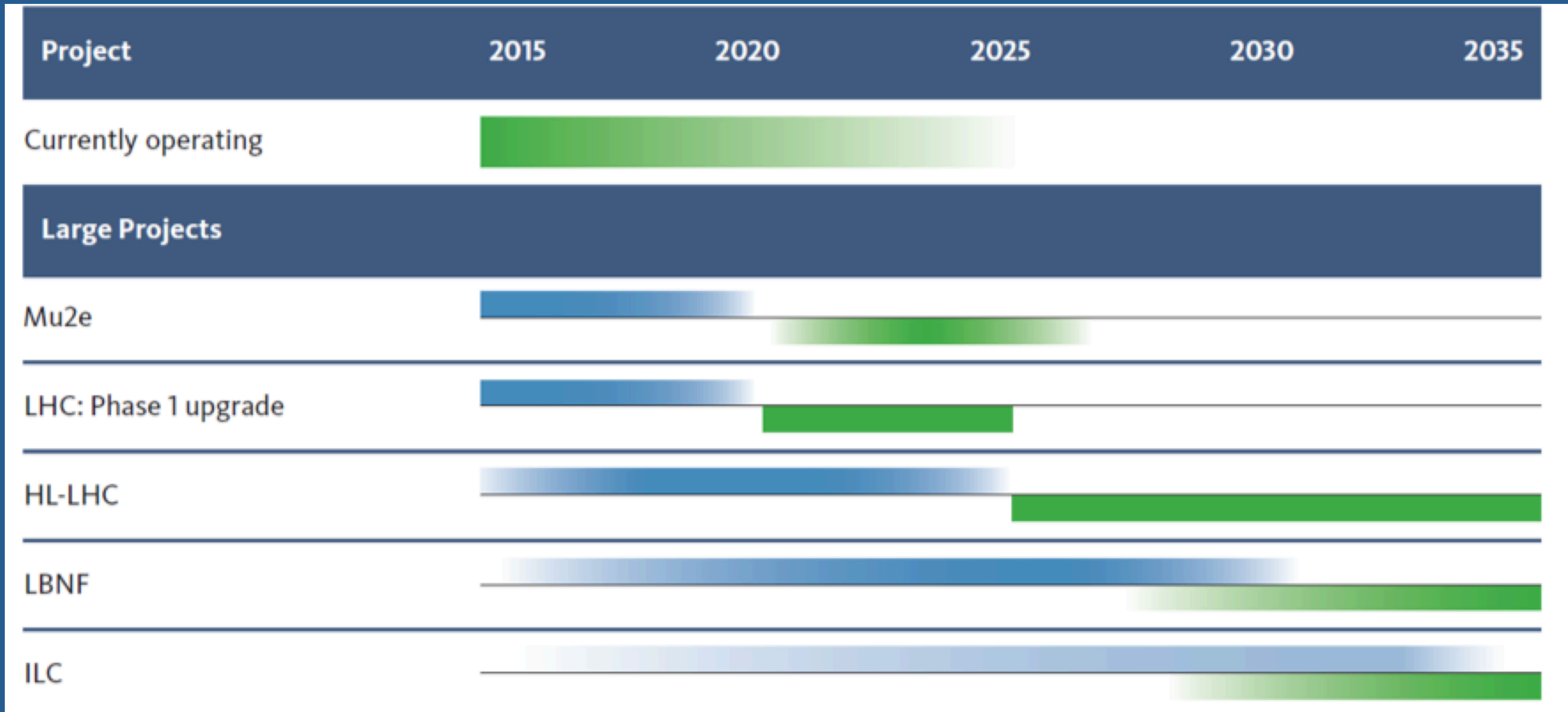
Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.

- CHIPS – CHerenkov In mine PitS (UK/US project)
- Water Cherenkov in NuMI beam NOvA -- arXiv:1307.5918

  Not recommended by P5, but R&D supported by DOE.

  Prototype to be deployed in Wentworth Pit this Summer

Timeline



- DOE timeline presented by Jim Siegrist at this meeting.
- Extension of timeline in potential conflict with internationalisation.

LBL neutrino physics – a worldwide priority

- **Use the Higgs boson as a new tool for discovery**
- **Pursue the physics associated with neutrino mass**
- **Identify the new physics of dark matter**
- **Understand cosmic acceleration: dark energy and inflation**
- **Explore the unknown: new particles, interactions, and physical principles.**

P5 Report (2014, USA)

Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*

European Strategy Update

European Strategy (2013)

Summary

LBNE has a world-leading physics programme with the potential to make fundamental discoveries in the areas of leptonic CP violation, neutrino masses, proton decay, and supernova neutrinos.

An international Long Baseline Neutrino Experiment hosted at Fermilab will deliver the essential components of this project:

- A high intensity neutrino beam
- A high resolution near detector system
- A liquid argon underground Far Detector with >35kt mass

LBNE is actively engaged with new international partners (scientists and government agencies) with the goal to internationalize the design, funding, construction, and operation of the facility.

LBNE enthusiastically welcomes the creation of an international organizational structure and will be engaged in its formulation.

Backup

Assumptions on Detector Performance

Parameter	Range of Values	Value Used for LBNE Sensitivities
		For ν_e-CC appearance studies
ν_e-CC efficiency	70-95%	80%
ν_μ-NC misidentification rate	0.4-2.0%	1%
ν_μ-CC misidentification rate	0.5-2.0%	1%
Other background	0%	0%
Signal normalization error	1-5%	1-5%
Background normalization error	2-15%	5-15%
		For ν_μ-CC disappearance studies
ν_μ-CC efficiency	80-95%	85%
ν_μ-NC misidentification rate	0.5–10%	1%
Other background	0%	0%
Signal normalization error	1-10%	5–10%
Background normalization error	2-20%	10-20%
		For ν-NC disappearance studies
ν-NC efficiency	70-95%	90%
ν_μ-CC misidentification rate	2-10%	10%
ν_e-CC misidentification rate	1-10%	10%
Other background	0%	0%
Signal normalization error	1-5%	under study
Background normalization error	2-10%	under study
		Neutrino energy resolutions
ν_e-CC energy resolution	$15\%/\sqrt{E(GeV)}$	$15\%/\sqrt{E(GeV)}$
ν_μ-CC energy resolution	$20\%/\sqrt{E(GeV)}$	$20\%/\sqrt{E(GeV)}$
E_{ν_e} scale uncertainty	under study	under study
E_{ν_μ} scale uncertainty	1-5%	2%

Assumptions for Beam Parameters

- **Conceptual Design Report (CDR) Beam:**
  - Ep = 120 GeV, 700kW
  - Graphite target 96cm long
  - Target -35cm from Horn 1
  - NuMI horns, 6.6m apart, 200kA
  - Decay pipe dxl = 4x200m, air filled
- **80 GeV Beam:**
  - Ep = 80 GeV, 700 kW
  - Be target 85cm long
  - Target -25cm from Horn 1
  - NuMI horns, 6.6m apart, 230kA
  - Decay pipe dxl = 6x250m, evacuated

- 80 GeV Beam gives 50% more flux at 1st and 2nd nodes.